"Readiness through Knowledge"

Headquarters Air Weather Service

Aerospace Sciences Division

Providing Service Worldwide

FYI

April 1997 Number 39

LIGHTNING

Headquarters Air Weather Service
Aerospace Sciences Division
102 W. Losey Street
Scott Air Force Base, Illinois 62225-5206

FYI

Information for Air Force Weather (AFW)

Number 39
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Published by Air Weather Service, FYIs are intended to provide general information to Air Force Weather (AFW)

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REPORT DOCUMENTATION PAGE	*Form Approved OMB No. 0704-0188*

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE April 1997	3. REPORT TYPE AND DATES COVERED

4. TITLE AND SUBTITLE FYI 39, Lightning	5. FUNDING NUMBERS
6. AUTHOR(S) Capt Maria Reymann	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) HQ AWS/XON 102 W Losey Street Room 105 Scott AFB, IL 62225-5206	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION AVAILABILITY STATEMENT	12b. DISTRIBUTION CODE
Approved for public release; distribution is unlimited.	

13. ABSTRACT *(Maximum 200 words)*

Air Force Weather (AFW) currently uses a variety of stand-alone lightning mapping systems and regional lightning mapping networks to provide a wide range of support to both the Air Force and the Army. The data from these stand-alone systems and networks enable personnel to warn and advise on lightning hazards, not only for aircraft operations but also resource protection.

This FYI provides information on lightning and its effects on operations. It discusses lightning detection systems and forecasting tips that you may want to integrate into your operations to help you warn your customers of lightning hazards.

14. SUBJECT TERMS	15. NUMBER OF PAGES
Lightning detection systems, Lightning climatology, Probability of lightning Conditions, Lightning forecasting	11
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	

LIGHTNING

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INTRODUCTION

Air Force Weather (AFW) currently uses a variety of stand-alone lightning mapping systems and regional lightning mapping networks to provide a wide range of support to both the Air Force and the Army. The data from these stand-alone systems and networks enable personnel to warn and advise on lightning hazards, not only for aircraft operations but also resource protection.

This FYI provides information on lightning and its effects on operations. It discusses lightning detection systems and forecasting tips that you may want to integrate into your operations to help you warn your customers of lightning hazards.

"A lightning strike can kill, destroy equipment, start fires, and disturb power systems. On annual average, lightning is the leading cause of weather-related fatalities and injuries."

☑ Causes

As a thunderstorm grows, electrical charges build up within the cloud (Figure 1). For reasons not yet completely understood, millions of collisions occur between ice crystals and large ice particles, and storms evolve with positive charges near the top and negative charges from the middle to the cloud base. Lightning results from the buildup and discharge of energy between these two charged areas. In a typical cloud-to-ground strike, negative charges descend from cloud base to ground. Trees, poles, and other objects respond with a positive charge upward. Lightning discharges can occur cloud-to-cloud, cloud-to-air, and cloud-to-ground. The majority of the strikes occur within the cloud, while only about 20 percent occur between cloud to ground. Each stroke can heat the air to 30,000°C and lasts fractions of a second.

☑ Ground Operations

Cloud-to-ground lightning has the greatest impact on our daily lives. About 90 percent of cloud-to-ground flashes are negative charge and descend from the cloud base to the ground. The negative cloud-to-ground lightning flash is broken into three stages:

- Step leader.
- Return stroke.
- Dart leader.

When a charge is strong enough, a stream of weakly charged particles moves downward out of the cloud. Because air is a poor conductor, the stream stops and starts in a series of steps looking for the path of least resistance--hence the name step leader. If a step leader nears the ground, a surface-based streamer comprised of oppositely charged particles rises up to meet it. When the leader and the streamer

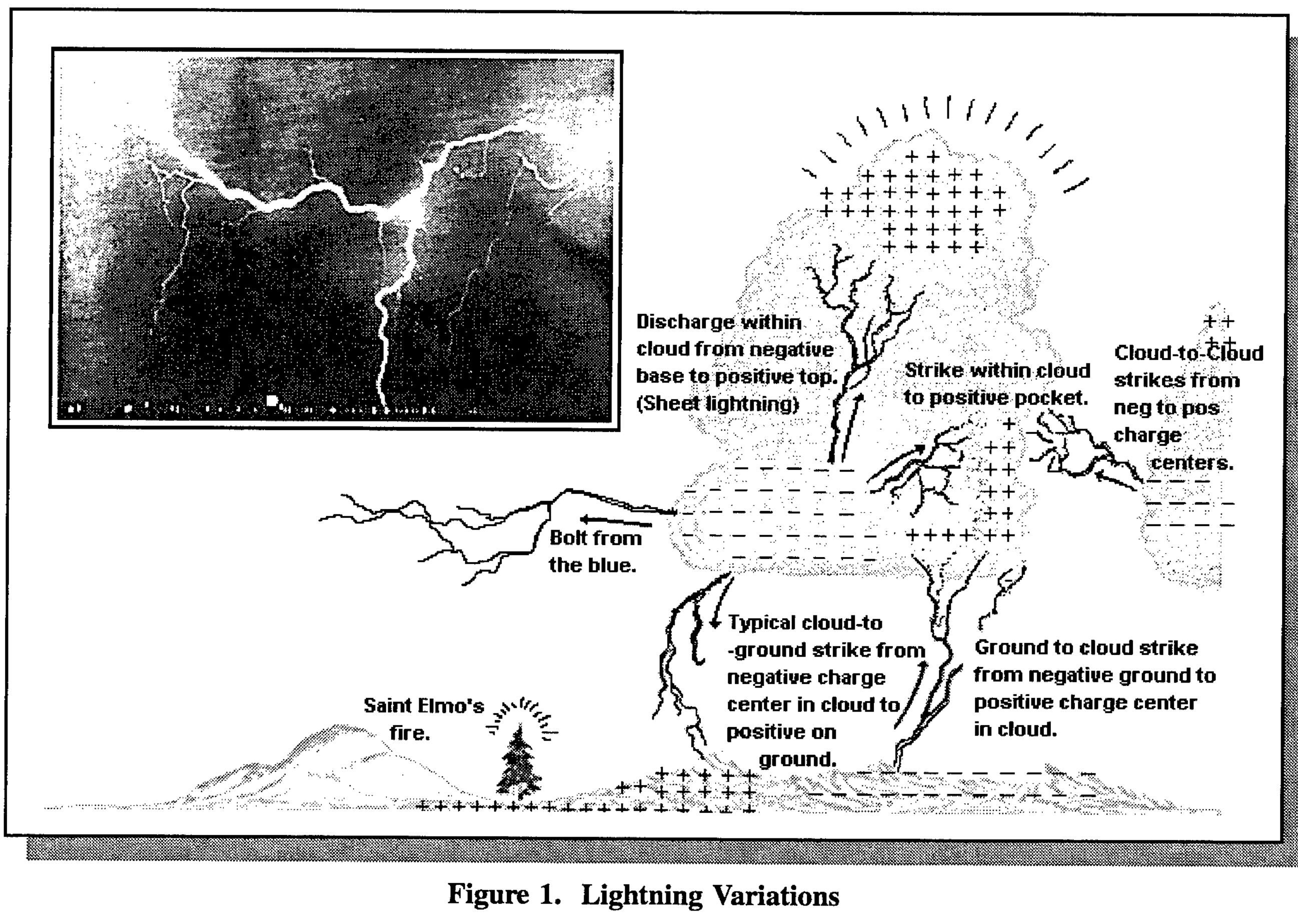

Figure 1. Lightning Variations

meet, the circuit is complete and we see a flash of lightning. This is the return stroke that travels from the ground to the cloud so quickly that we cannot see which way it is going. After the initial return stroke, several flashes occur along the same path; the "dart leader" comes down from the cloud following a direct path to the surface. In turn, the dart leader triggers a second return stroke.

The other 10 percent are positive lightning strokes. These travel from near the cirrus anvil at the top of thunderstorms or from "clear" air near the mid- or upper-part of the storm cloud to the ground. These strikes are most intense and seem to come from "out-of-the-blue." They are also composed of a single stroke and have longer continuing currents. These charges are usually found near the top of the cloud, however, they can be found in the cloud base if the freezing level is low enough. The percentage of positive strokes appears to increase with latitude and with the height of the local terrain. Positive flashes are also more common in winter storms. (The lower freezing level may place the positive charge closer to the ground.)

Positive flashes are more common in stratiform clouds while negative flashes tend to occur in areas of strong convection. Also thunderstorms that consist of negative flashes in their early stages often end with positive discharges as the storm matures and the anvil spreads out.

A lightning strike can kill, destroy equipment, start fires, and disturb power systems. On annual average, lightning is the leading cause of weather-related fatalities and injuries. Annual property damage estimates from lightning, excluding forest fires, are almost $2 billion dollars (National Lightning Safety Institute). Lightning strikes and electrostatic discharges are the leading causes of reportable weather-related aircraft accidents and incidents in the Air Force.

☑ Air Operations

Air operations are impacted by direct lightning strikes, triggered strikes, and electrostatic discharges. Aircraft and rockets can trigger lightning strikes with non-electrically active clouds because the clouds are full of charged water droplets and ice crystals. The discharge results from the interaction between the aircraft or rocket and the cloud. This most commonly happens in convective-type clouds that have not matured.

There are a number of low-level locations that increase the potential for triggered lightning strikes:

- In cloud and precipitation at flight levels where the air temperature is between –8°C and +8°C. These temperatures occur at flight levels within 5,000 feet (above or below) the freezing level.
- Near the vicinity of large downdrafts. This coincides with turbulence in convective precipitation.
- In high dust or pollution rich environments.

There are also high-level locations that increase the potential for triggered lightning strikes:

- At temperatures colder than –32°C and at flight levels above 28,000 feet.
- In thunderstorm-generated cirrus even after the thunderstorm dissipates.
- Lack of turbulence at high levels.

Lightning has struck aircraft as far as 50 miles from a storm at altitudes as high as 38,000 feet. Aircraft flying in Europe experience aircraft strikes 3 1/2 to 10 times more often than the US since its lightning strike range is at lower altitudes due to the more northern latitudes. Europe's range is generally from 20,000 to 25,000 feet in winter and 24,000 to 30,000 feet in summer. For all locations the average temperature at strike time is –30°C and the peak number of strikes occurs at –42°C.

Electrostatic discharges occur when the charge centers are smaller. Static dischargers are now on some aircraft and they drain off the accumulated electrical charge; however, they neither protect the aircraft from lightning nor reduce the probability of a strike. Generally, the heavier the precipitation, the greater the chance of electrostatic discharge.

Structural damage is minor with electrostatic discharges; however, severe damage can occur with natural or triggered lightning. Electrostatic discharges usually cause only minor physical damage and indirect effects such as electrical circuitry upsets. Damage to aircraft electrical systems, instruments, avionics, and radar are not unusual with a lightning strike.

☑ Lightning Detection

Garrison and tactical weather units need access to cloud-to-ground lightning data. However, cloud-to-cloud data is also important because it can help forewarn forecasters and customers of the imminent danger of cloud-to-ground lightning.

National Networks

In the 1980s, there were several networks covering the United States. In 1994, the networks combined into one national network, the National Lightning Detection Network (NLDN) operated by Global Atmospherics. Networks also exist over Europe, Asia, Australia, China, Canada and South America. The networks consist of multiple direction finders that cover an entire area. Each of these sensors is capable of detecting cloud-to-ground and cloud-to-cloud lightning strokes. Within seconds of the stroke, the system informs you of latitude and longitude, time of the stroke, polarity, peak amplitude, rise time, direction, and derived speed of storm. Most networks are accurate to 1 or 2 km out to a 200 km range; however, this is dependent consistency of location data and detection efficiency. Networks can help you track a cell and lightning as it approaches your station and influences your local weather. They can also help you Metwatch many different flights and bases and track large systems as they move towards you. Networks, however, are not as accurate as individual sensors in advising you of lightning in your local area.

Single Sensors/Local Networks

There are numerous local area coverage products that may help you forecast or advise of lightning. Electric field mills sense the vertical electrostatic field in developing or approaching thunderstorms within a 10-mile radius. Field mills should not be used as lightning detectors but to detect the evolution or presence of thunderstorms near the site. It alerts the user to the **threat** of a first strike and/or cloud-to-ground strikes(s) emanating from an anvil cloud. It also monitors the atmospheric potential field to see if it is returning to a stable profile as cells dissipate or move out of the area of concern.

Also available are short-range, stand-alone thunderstorm sensors specifically designed to classify lightning discharges while addressing personal safety and property protection to your base. Many of these individual sensors only sense discharges out 30-50 km, however most are 90 percent accurate within 5 miles. Multiple local sensors combined with national networks give you an excellent local network and increase the accuracy and range of the discharges. Many of these local networks are 80-90 percent accurate within 50-100 km. The combination of both local sensors and networks give you precise

For further information on acquiring the National Lightning Detection Network

Please call AWS/SYD SMSgt Haines at DSN 576-3268 ext. 313.

Note: Initial cost of acquiring the system is roughly $10,000 with a $4,000 yearly cost.

information to inform your customers of the local hazards that may affect your base.

Note: Accuracy of 90 percent means it detects 90 percent of the actual strikes within an area. The above statistics are from the lightning detection vendors.

LIGHTNING CLIMATOLOGY

Figures 2 - 6 give the average number of thunderstorm days per year for Air Force Weather Stations around the globe. The isolines on each map are based on Air Force Combat Climatology Center's (AFCCC) thunderday climatology and Uman (1987). In the middle latitudes, North America receives the most lightning due to its unique geography conducive to thunderstorms. Two US regions are most prone to strikes. Florida with its peninsular shape causing ocean-land heat contrast and boundary layer convergence that triggers storms. The high plains and foothills of the Rocky Mountains receive intense summer lightning due to elevated heating, moisture from the Gulf of Mexico, and high altitude. Thunderstorm days are not the ideal index of lightning, since it does not distinguish between a single strike of lightning and a prolonged storm.

AFCCC has also developed a computer program (PC-0056) with data obtained from NLDN to display cloud-to-ground lightning strike climatology for the US. It can be displayed as either bar graphs or isopleth analysis for eight regions (West Coast, Northern Plains, Great Lakes, Northeast, Southwest, South Central, Southeast and East Coast) as well as the entire CONUS. Examples are on pages 11 and 12. To receive a copy of this software call the AWS Technical Library at DSN 576-5023.

PROBABILITY OF LIGHTNING CONDITIONS

Many units use the Probability of Lightning Conditions (POLC) to help them warn of potential lightning hazards. POLC does not mean the probability of being struck by lightning. It means the probable existence of various conditions necessary for lightning or electrical discharges in a flight area.

To figure out the POLC, see the tables on page 8. Then review all the factors to come up with the POLC. Add or subtract the positive and negative percentages at each step to give you a POLC total. If the total is equal to or less than 50 percent, POLC is usually not briefed. Remember that a POLC of 100 percent does not mean lightning will strike the aircraft.

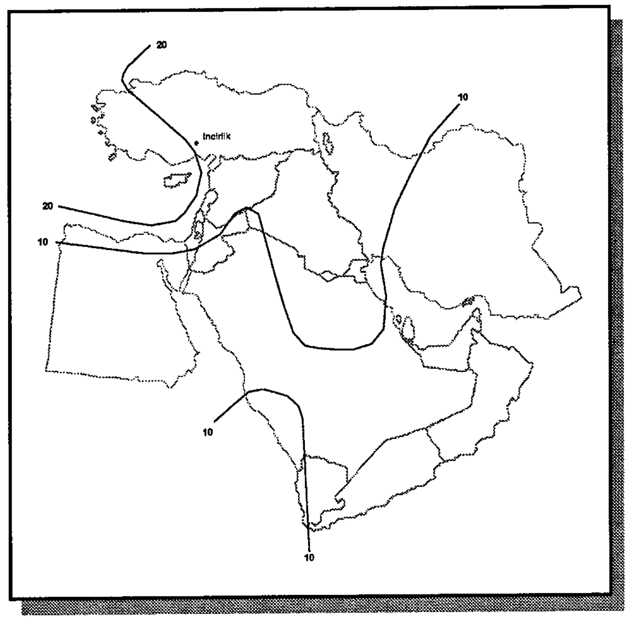

Figure 2. Southwest Asia Thunderstorm Climatology

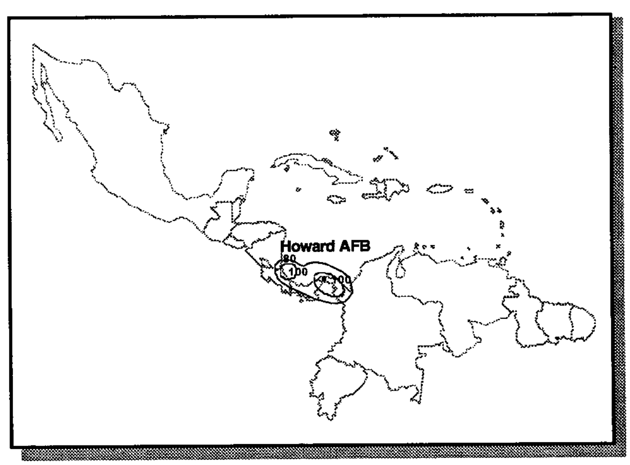

Figure 3. Central America Thunderstorm Climatology

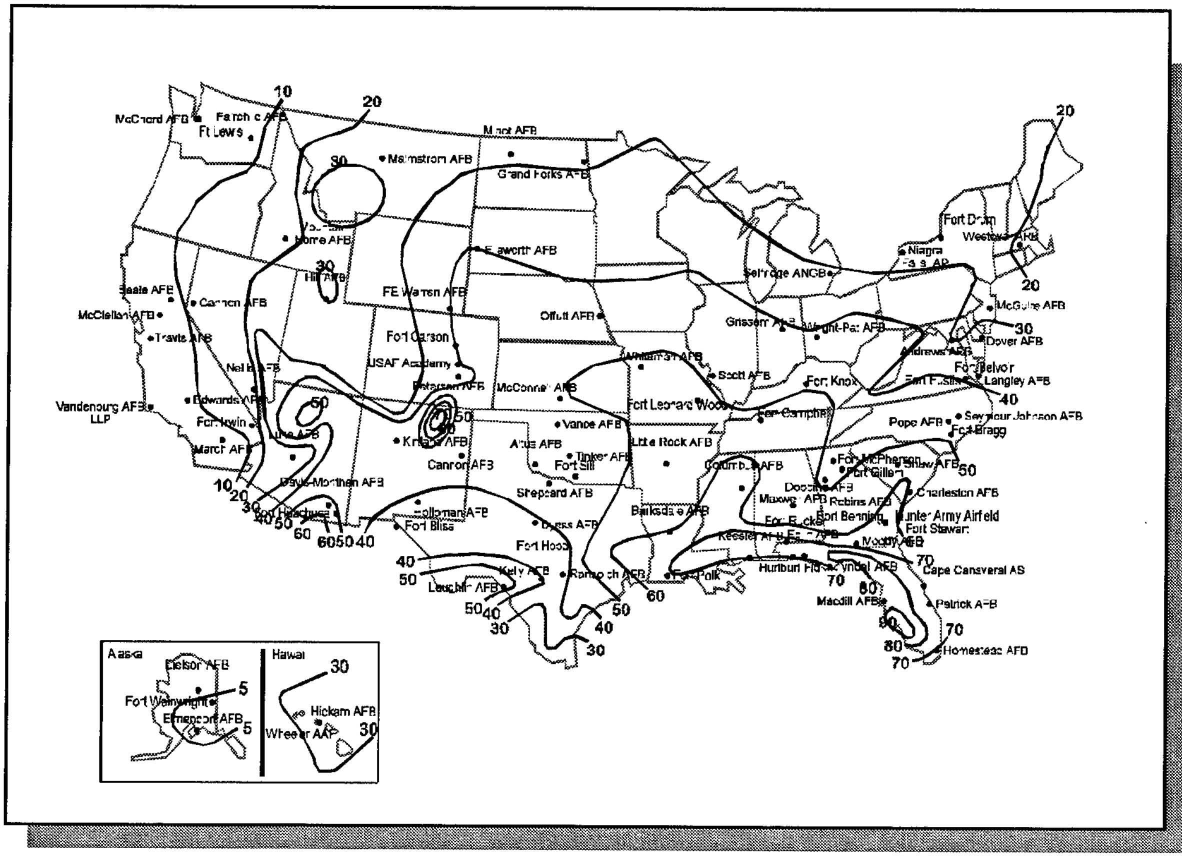

Figure 4. US Thunderstorm Climatology

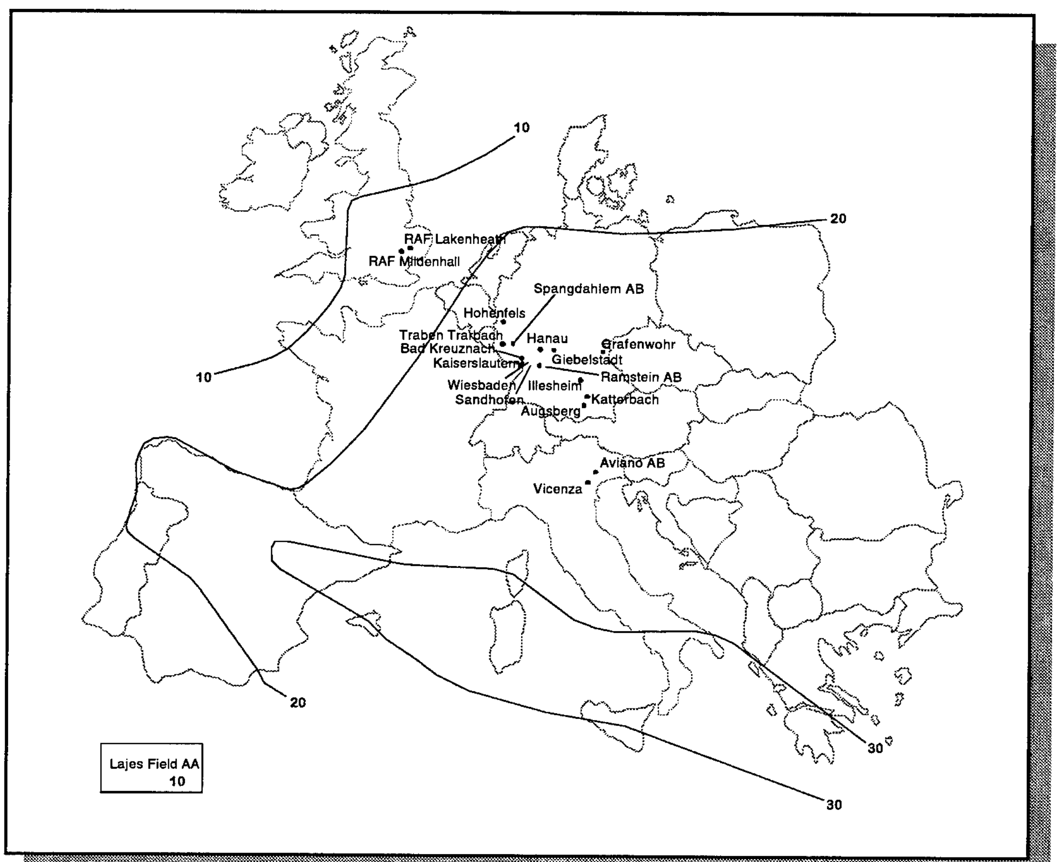

Figure 5. Europe Thunderstorm Climatology

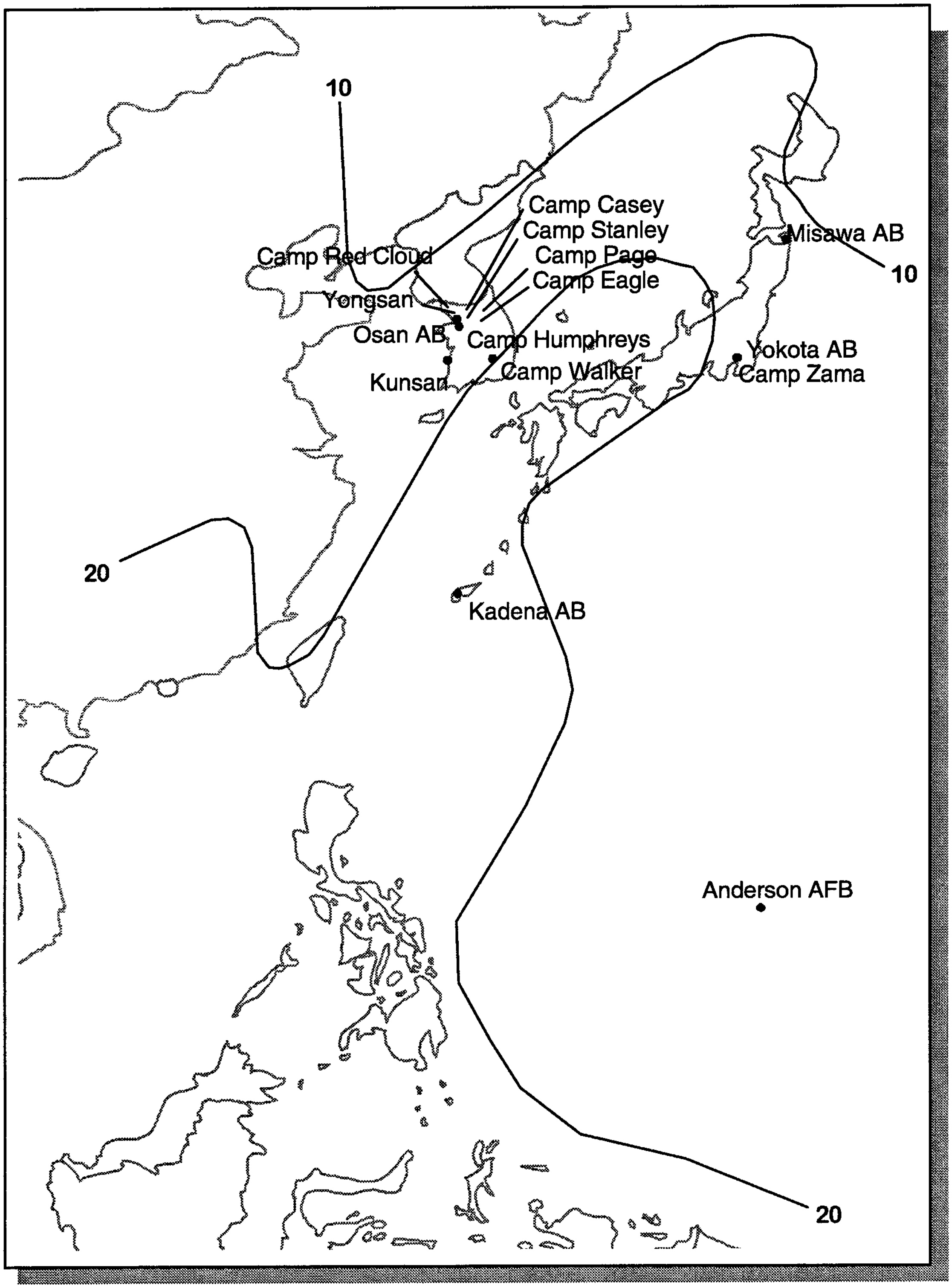

Figure 6. Western Pacific Region Thunderstorm Climatology

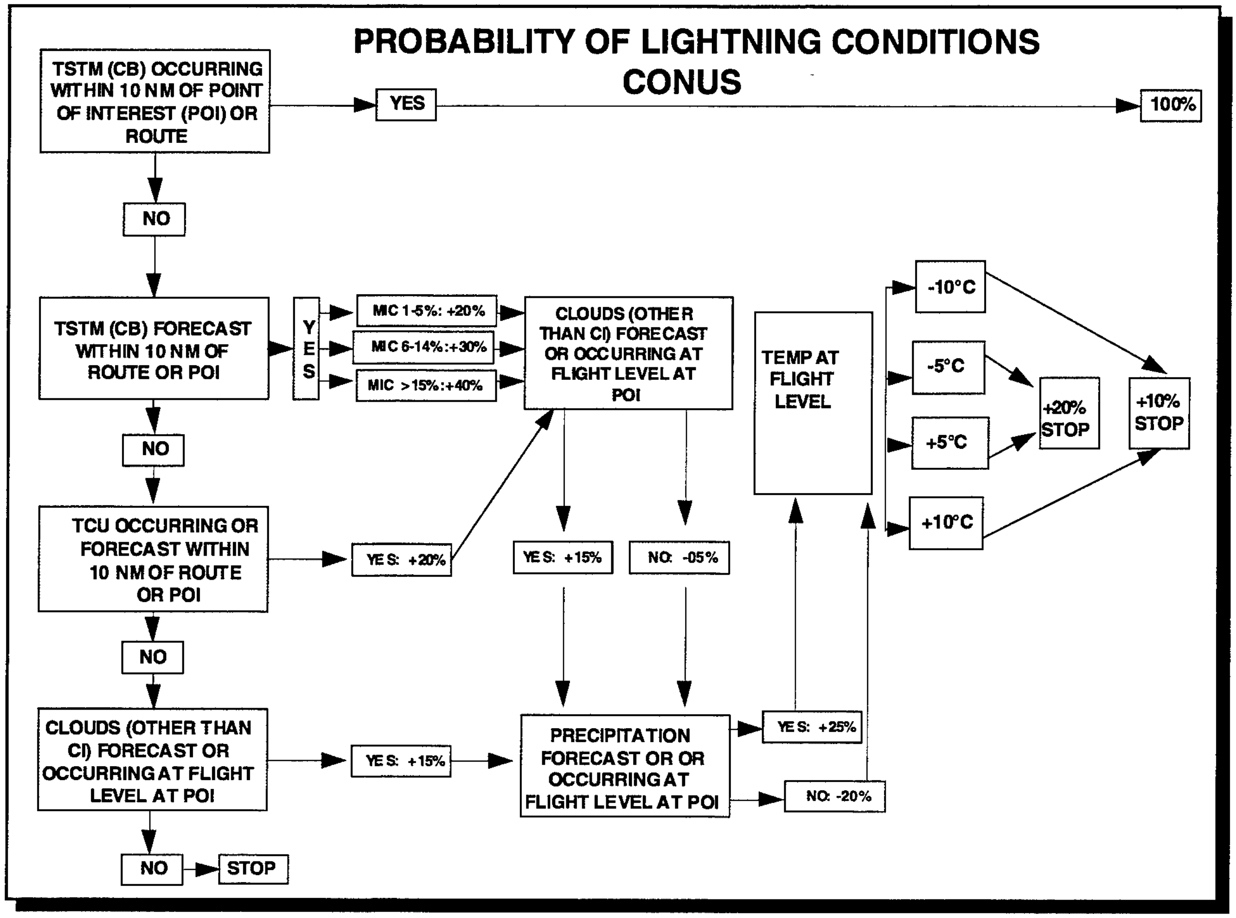

Figure 8. POLC for CONUS

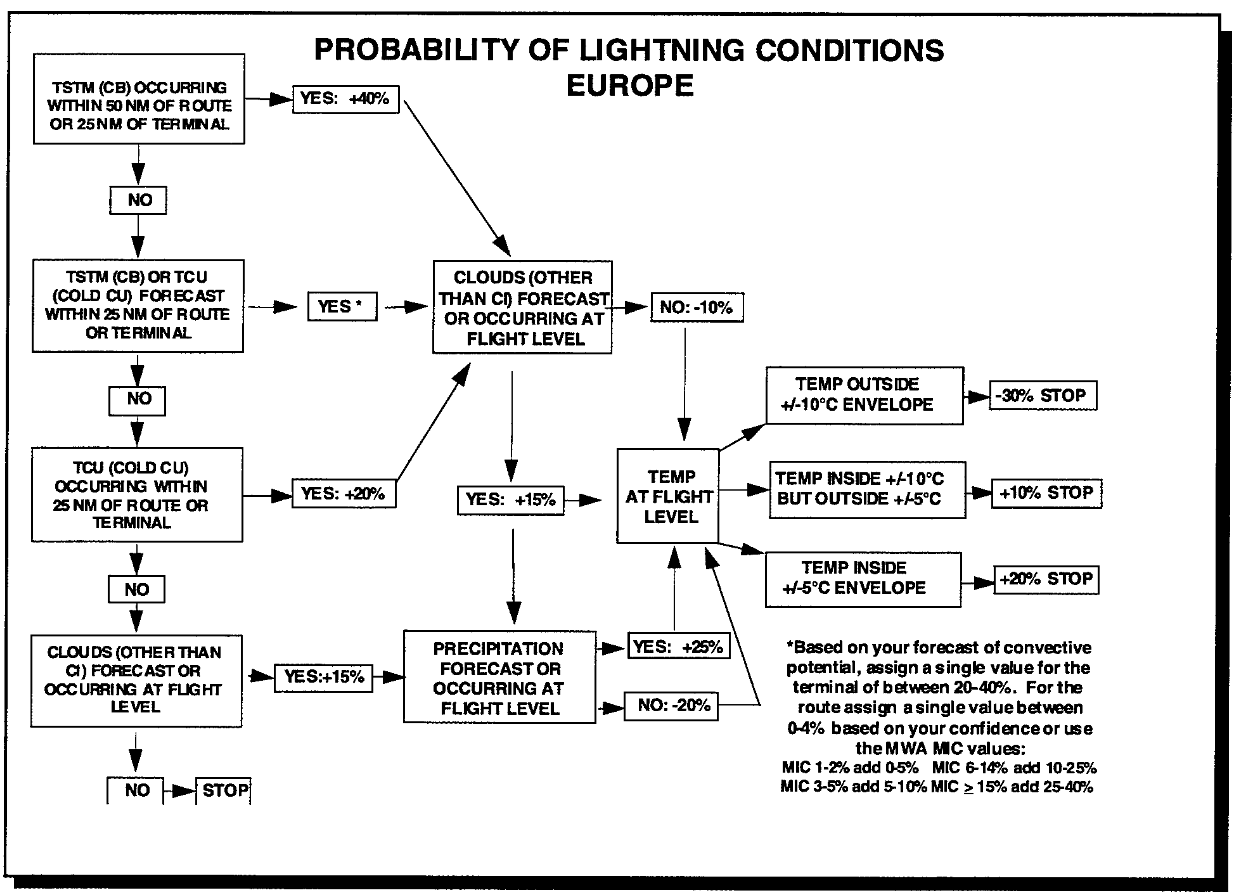

Figure 7. POLC for Europe

Lightning Data and Your Forecast

The field of lightning research is only beginning to reveal ways in which knowledge of lightning frequency, polarity, and distribution may provide valuable information to the forecaster. Lightning data can supplement radar data, satellite imagery, and surface observations in the confirmation of a particular cell as a thunderstorm. In areas where radar and surface data are sparse, lightning data may prove to be the only information available for determining thunderstorm presence and intensity.

It is important to remember that radar can detect varying rates of precipitation but not lightning when the radar operator reports a thunderstorm. They are making an educated guess based on the characteristics of certain cells. Lightning can help confirm that a particular cell is a thunderstorm; there are situations where cells with only modest tops produce lightning and situations where cells with up to 45,000 feet tops produce no lightning. On a real-time basis the lightning data can help the forecaster identify cells and lines of cells embedded in radar echo returns. Finally, lightning data can detect lightning before the first echoes appear on radar.

It is often difficult to distinguish cloud areas or cells that are thunderstorms from those that are not when using satellite imagery. It is often difficult to identify the convective areas of thunderstorm systems as they mature and dissipate. Anvil cirrus blow-off usually obscures individual active cells in all but the super-rapid scan mode of geostationary satellites. Infrared (IR) imagery, with its various enhancement curves, will often help in the indication of active cells; however, not all active cells produce lightning. Many lightning experts have written articles that help to correspond the relationship of lightning discharges to IR cloud top pixel intensities. This relationship enhances the identification and short-term forecasting of squall lines, cold fronts, and orographically induced activity.

Forecasting Lightning

Radar and satellite imagery are only beginning to be integrated into lightning forecasting.

Radar

There is an association between radar reflectivity and negatively charged lightning flashes. Lightning discharge sources are located near, but not necessarily within, the area of highest reflectivity. In two studies by Mazur (1983) and Mazur and Rust (1985), they found that the region of maximum lightning flash density was close to the leading edge of the precipitation core, defined by 50 dBZ on the radar reflectivity. Lopez, Otto, Oritiz, and Holle (1990) confirmed that in a Colorado thunderstorm, the peak lightning activity occurs in the gradient areas of high reflectivity.

Satellite Imagery

Although there are currently no techniques to use satellite imagery to help you forecast lightning, NASA is developing a Lightning Mapper Sensor to be part of GOES-M at the Marshall Space Flight Center (launched before the year 2000). This should enable forecasters to view all of the lightning in a large area, allowing forecasters to track large storms for large distances and track their life cycles. Satellite lightning researchers hope to correlate an increase in lightning and storm size, the amount of rainfall, and the frequency of lightning. This should help provide an understanding of the way lightning is generated.

Advising Lightning

Due to incidents that occurred last year, lightning policy was discussed at the Air Force Lightning Safety Panel, the AWS Lightning Integrated Process Team (IPT), and the AFW Severe Weather IPT. The following is an excerpt from the draft of AFOSH 91-66.

According to the draft AFOSH 91-66, the base weather station is responsible for making the initial notification to predetermined support agencies of adverse weather conditions. Each Air Force installation must develop a local procedure to ensure that key personnel and agencies are notified according to the base weather support plan. Normally, these agencies are those having aircraft, petroleum/oil/lubricant (POL) facilities, open air work, recreational activities, and underground utilities work. Key personnel, in turn, advise all on-duty supervisors to take proper precautions and timely actions.

Each installation will employ a lightning safety program with a two-tiered notification system to minimize personnel exposure to lightning hazards.

Lightning Watch

A Lightning Watch is in effect 30 minutes prior to thunderstorms being within a 5 nautical mile radius of any predetermined location or activity as forecast by the base weather station.

During a Lightning Watch accomplish the following:
- Operations or activities may continue, however, all personnel must be prepared to implement Lightning Warning procedures without delay.
- Be alert for any lightning activity, to include audible thunder, and advise supervisory personnel of any observations.

Lightning Warning

A Lightning Warning is in effect whenever any lightning is occurring within a 5 nautical mile radius of the predetermined locations and activities. Personnel in affected locations or engaged in affected activities will take the following actions:
- Cease all outside activity and seek shelter. Recommended locations that provide safe shelter and locations to avoid are listed in the table below.

If lightning does not occur within 5 nautical miles at the valid (forecast) time of the Lightning Watch, then the base weather station should reassess the Lightning Watch and amend as needed. Lightning Warnings will be canceled when thunderstorms have passed beyond the 5 nautical mile radius of the location or activity. A Lightning Watch **will not** be canceled if there is potential for more thunderstorms within 30 minutes.

Note: Lightning is a direct product of a thunderstorm.

CONCLUSION

Advising and warning our customers of lightning continues to be one of our biggest challenges. By using documented techniques and exploiting our evolving technologies, we can develop useful tools to advise our customer of the hazards of lightning.

Whenever lightning is detected or observed within the immediate vicinity of any activity or operation, the following precautions should be taken:

Do not go outdoors or remain out unless it is absolutely necessary. Seek shelter as follows:
- Dwellings or other buildings that are protected against lightning.
- Protected underground shelters.
- Large metal-framed buildings.
- Enclosed automobiles, buses and other vehicles with metal tops and bodies.
- Streets that may be shielded by nearby buildings.

Certain locations are extremely hazardous during thunderstorms and should be avoided:
- Hilltops and ridges, under isolated trees.
- Areas on top of buildings.
- Open fields, athletic fields, golf courses, parking lots, tennis courts, swimming pools, lakes, and seashores.
- Near wire fences, clotheslines, overhead wires, and railroad tracks.
- Near electrical appliances, telephones, plumbing fixtures, and metal/electrically conductive objects.

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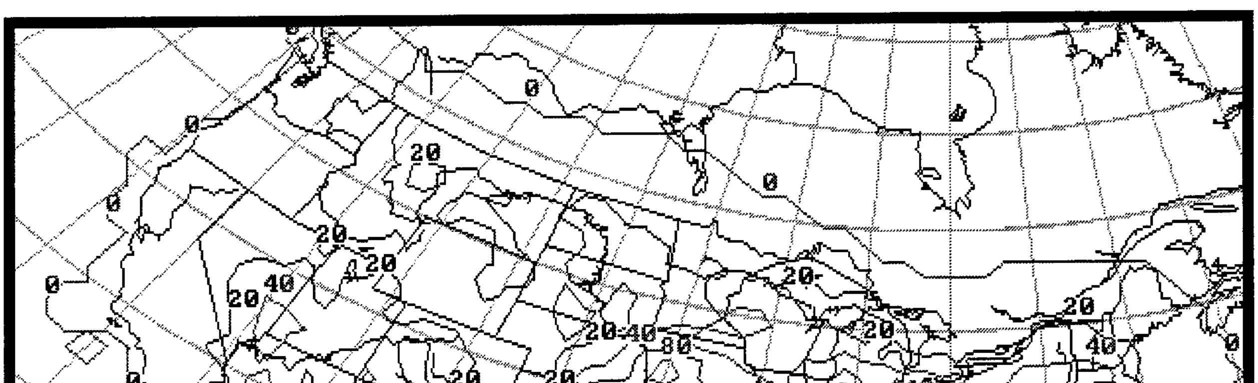

Example of AFCCC Lightning Climatology Program (PC-0056) CONUS Region. Analysis of the average hourly lightning strikes for the CONUS Region for all hours March through October.

FYIs

FYI #9:	MOS Guidance	Nov 92
FYI #10:	Technical Improvement	Nov 92
FYI #11:	Commanders WX Info Pamphlet	Nov 92
FYI #12:	TAFVER	Nov 92
FYI #14:	Fixed Meteorological Equipment	Feb 93
FYI #16:	RVR-2	Feb 93
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FYI #21:	Medium-Range Forecast (MRF) Based Objective Forecast Message (OFM)	Jul 93
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FYI #23:	Conditional Climatology (CC) Tables	Sep 93
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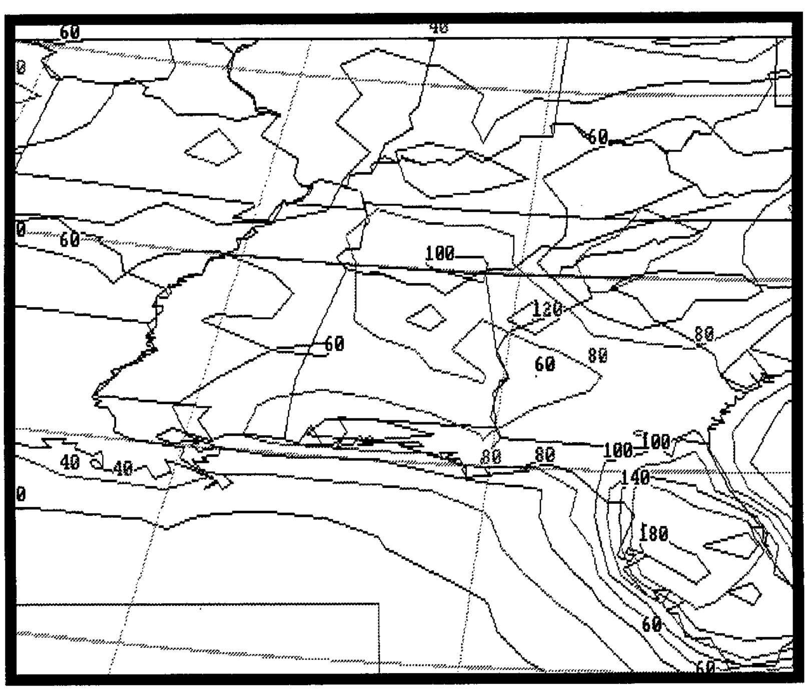
FYI #37:	Space Environmental Impacts on DoD Operations	Feb 97
FYI #38:	Icing	Mar 97
FYI #39:	Lightning	Apr 97



Example of AFCCC Lightning Climatology Program (PC-0056) Southeast Region. Analysis of the average hourly lightning strikes for the Southeast Region for all hours March through October.